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International Refrigeration and Air Conditioning Conference

School of Mechanical Engineering

2000

Refrigeration and Air Conditioning with Reduced Environmental Impact

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REFRIGERATION AND AIR CONDITIONING WITH REDUCED ENVIRONMENTAL IMPACT

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ABSTRACT

Manufacturers of refrigerants and refrigeration and air conditioning equipment, governmental agencies, and environmental groups continue working together toward the goal of reduced environmental impact via reduced emissions and improved energy efficiency. Examples of progress are presented for several sectors of refrigeration and air conditioning, followed by projections for further significant reductions.

Working fluid selection for the myriad of refrigeration and air conditioning applications is based on three factors: safety (toxicity and flammability), environmental impact (stratospheric ozone and climate change), and performance (cooling and heating with required capacity, energy efficiency, reliability, and cost effectiveness). Although this paper will emphasize environmental impact for fluid selection, all of the factors must be evaluated to determine the most appropriate fluid for each application.

INTRODUCTION

Hydrofluorocarbon (HFC) working fluids have been mainly chosen to replace chlorofluorocarbons (CFCs) in refrigeration and air conditioning due to high merits in safety, performance, and no effect on ozone depletion. HFC compounds generally have lower global warming potential values than CFCs, but these values are higher than for fluids such as ammonia, hydrocarbons, and carbon dioxide. To minimize the impact of HFCs on climate change, it is important for industry to continue improving stewardship-in-use practices. This includes selection of HFCs for applications with high societal value, and cradle-to-grave management of emissions during HFC production, transportation, use, equipment servicing, and final recovery. Refrigeration and air conditioning equipment is being designed and operated for reduced HFC emissions, and with improved energy efficiency for reduced carbon dioxide emissions.

ENERGY EFFICIENCY AND EMISSIONS

Unlike the situation with stratospheric ozone depletion in which chlorine containing compounds are being phased out to protect the ozone layer, climate change discussions are appropriately focused on emissions. The Kyoto Protocol is based on a "basket of gases" so no single class of gases must be targeted for phase out. HFC compounds have a range of global warming potential values and are included in the basket. For the high societal value refrigeration and air conditioning applications, HFCs are prime candidates for reducing net emissions within the basket of gases. Very specifically, at equivalent costs of other options, climate change impact from minimal refrigerant emissions can be more than offset by improved energy efficiency (thereby reducing CO_2 emissions), while meeting reliability and safety requirements. As one example, with a typical North American split system heat pump having a 5% annualized refrigerant loss, the refrigerant climate change impact can be offset by a 5% increase in energy efficiency. This well-known approach has been described in many publications (examples being 1,2). The following sections describe a progression of energy efficiency improvements and refrigerant emission reductions, demonstrating industry capability and commitment to produce and operate refrigeration and air conditioning systems with a continuing reduction in environmental impact.

ENERGY EFFICIENCY IMPROVEMENTS

Refrigeration and air conditioning system energy efficiency has been steadily improved by manufacturers due to several driving forces: environmental group actions to increase awareness of concerns about climate change, increasing focus on reducing energy costs, governmental regulations, and market opportunities for product differentiation. These forces were important factors before the Montreal Protocol, and now have become even more critical due to global climate change. Several examples of energy efficiency improvements in the United States refrigeration and air conditioning markets follow. It is essential to note that energy efficiency improvements have continued through the time of the transition from CFCs, proving that HFCs provide the same or better energy efficiency than CFCs. Supporting references can be found in several publications (3,4).

Domestic Refrigerator-freezer

Domestic refrigerator-freezer energy consumption in the United States has decreased from 1750 kWh/year in 1972 to 700 kWh/year in 1993, a decrease of 60% (5) (Figure 1). These values are for a typical size unit of 20 ft^3 (570 liter). Governmental standards in 1990 and 1993 assisted in continuance of the downward trends. One manufacturer of refrigerator-freezers introduced a unit in 1995 that meets the projected 2001 energy efficiency standards: a reduction of 30% in energy consumption. The energy consumption for this appliance is equivalent to that of a 60 watt light bulb.

Unitary Air Conditioning

Similar improvements in energy efficiency have occurred in unitary air conditioning products (6). Figure 2 illustrates the (shipment weighted) energy efficiency ratings of unitary air conditioners in the United States, with improvement from 7 to 10.8 SEER (energy efficiency ratio) from 1975 to 1995. This represents a reduction in energy consumption of 35%. Again, governmental regulations and market competition were major reasons for the improvement. Increased energy efficiency standards of about 20% are expected to be announced in 2001, becoming effective in 2006.

Centrifugal Chillers

Centrifugal chiller manufacturers have made significant improvements in chiller efficiency as shown in Figure 3 (7). Data for the highest efficiency chillers show a 33% reduction in energy consumption from 1978 to 1998. The highest energy efficiency chillers operate with the low pressure refrigerants CFC-11 and now HCFC-123. The reasons for high energy efficiency are based on refrigerant thermodynamic properties and equipment design features such as the use of multiple stage, direct drive compressors. Further reductions in power consumption from the present 0.48 kW/Ton to 0.45 kW/Ton are expected by 2005 (8).

Auto Air Conditioning

There has been minor concern for auto air conditioning energy efficiency over the years, as system run time and fuel to operate the air conditioning systems are relatively low values. Estimates of system operating times are 67 hours/year in Japan to 107 hours/year in North America (9), and gasoline to operate the air conditioning systems is about 3.3% of yearly vehicle gasoline consumption in the United States (10). However, with current research underway on potential use of hydrocarbons or carbon dioxide in auto air conditioning, attention is being given to total environmental impact of systems operating with HFC-134a refrigerant (refrigerant emissions and energy consumption).

A recent publication (10) contains an analysis of options to reduce auto air conditioning environmental impact, concluding that energy efficiency of systems operating with HFC-134a can be realistically increased by 53% under idle conditions and by 38% under down the road conditions. The realistic improvements included increased compressor efficiency, heat exchanger design changes, and lubricant containment in the compressor. Combining these improvements with reduced refrigerant emissions and operation with 50% recirculated air, the climate change impact of the HFC-134a system is somewhat lower than that of carbon dioxide systems. There are other considerations in the debate between auto air conditioning systems based on HFC-134a and carbon dioxide (system reliability, first cost, maintenance costs), but these are beyond the scope of this paper.

REDUCED REFRIGERANT EMISSIONS

Emphasis in this section will be directed to refrigerant emissions from auto air conditioning and supermarket refrigeration systems, as they have had the highest amounts of leakage; however, low emission rates from other systems are briefly described. The projected long term reductions in emission rates for all the applications are based on industry commitment to low emission goals through equipment design, operating and maintenance procedures, refrigerant recovery, and appropriate governmental regulations.

Domestic Refrigerator-freezer

Domestic refrigerator-freezers are built with hermetic systems having refrigerant emissions mainly in the case of system damage. Calculations of climate change impact are often based on the small refrigerant charge not being recovered at the end of the useful life of the unit. For a typical North American refrigerator, this loss amounts to 2.4% of the total equivalent carbon dioxide emissions (11). This is similar to the 3% value of equivalent carbon dioxide emissions reported in a study of European refrigerators (12). Mandatory government requirements for refrigerant recovery will reduce refrigerant emissions by 75% such that the above loss rates will become 0.6% and 0.75%, respectively.

Centrifugal Chillers

Centrifugal chiller refrigerant emission rates have been dramatically reduced. Calm (13) reported historical emission rates (1980's) of 8% of total charge annually, with 10% additional loss when equipment was retired. At the time of Calm's report (1993) the emission rates had been reduced to 4% and 5%, respectively. A study (14) of HCFC-123 centrifugal chiller operation revealed annual loss rates of 0.46%, which is in agreement with an estimate of 0.5% (15) for a well-maintained chiller. With further technology changes the possibility exists for this total loss rate to be reduced to less than 0.1%, or a five fold improvement (16). It is important to note this is a total loss rate, which includes typical service and maintenance leakage but also accidental losses. Leak rates are dependent on system pressure, so refrigerants with lower boiling points (higher pressures) than HCFC-123 will require more attention to achieve these low emission rates.

Unitary Air Conditioning

Unitary air conditioning equipment (ducted residential unit with compressor and heat exchanger remotely located from the evaporator coil) historical emission rates have also been 8% of total charge annually (13), with disposal venting loss of 40%. United States governmental regulations for refrigerant recovery had reduced 1993 estimates to 4% for annual losses and 5-10% for disposal losses. A 1997 report (17) estimated year 2005 annual loss rates reduced to 2%. These reductions are possible through continuing industry efforts improving fitting integrity, service procedures, and systems designed with smaller charge sizes.

Auto Air Conditioning

Auto air conditioning refrigerant loss rates were estimated to be 35% of charge annually in the 1970's and 80's (18) due to service procedures followed with no awareness of potential environmental impact. This included procedures such as venting refrigerant during system repair, and top-off of leaking systems instead of leak repair. With the Montreal Protocol ratification, the United States Clean Air Act Amendments taking effect November 15, 1991, and follow-on regulations by the United States Environmental Protection Agency, auto air conditioning service organizations were required to recover refrigerant during equipment servicing. This included training and certification of repair personnel, use of approved recovery equipment, and record keeping. It was estimated in 1991 that refrigerant losses would be reduced 67% by improved refrigerant handling procedures (requirements) and better system containment.

Better system containment is being accomplished through attention to many details in systems using HFC-134a. Examples are use of hoses having lower permeation rates, improved fitting designs (gaskets, O-rings), and highly sensitive leak detection procedures used in checking components such as heat exchangers during manufacturing.

Estimates of auto air conditioning refrigerant emissions depend on the number of refrigerant recharges over the 12 year equipment lifetime, losses during servicing and at end of life recovery (19). Current estimates are a recharge of 40% of the charge at four year intervals, 6% service loss at each recharge, and 25% loss at end of life. This is calculated to be an annualized loss of 12% of the refrigerant charge.

Improvements are expected in refrigerant containment to one recharge of 40% at an eight year interval. With the other above assumptions in losses, this is calculated to be an annualized loss of 7.2% of the refrigerant charge. Future trends toward electric vehicles will permit hermetic air conditioning systems which will be nearly free of emissions.

Supermarket Refrigeration – Direct Expansion

Supermarket refrigeration systems have a similar history of refrigerant emissions: 30 to 50% loss of charge per year (20) in large systems having display cases located remotely from the compressor/condensing units. In addition to historical practices that did not require refrigerant recovery, a mid-sized supermarket in the United States is estimated to have 18 miles (29 km) of refrigerant piping and 16,000 connections, representing many opportunities for leaks (21).

The same regulations described in the section on **Auto Air Conditioning** were applied to supermarket refrigeration systems. A provision that particularly impacted the supermarket industry was requirement for leak repair of systems with refrigerant charge sizes over 50 pounds.

In working to reduce refrigerant losses, supermarket engineers identified and quantified leak sources. One study (21) described a series of leak reduction technologies and procedures that could be used by supermarket facilities personnel. Applying these technology and procedure changes resulted in refrigerant loss reductions of 50 to 80% versus previous operation for these types of supermarkets, which would calculate to be annual loss rates of 7 to 17% (if 35% previous). These lower loss rates are similar to data from other sources (22) reporting 1996 ranges of 12 to 15%, with lowest possible future rates estimated to be 4 to 8%.

Supermarket Refrigeration – Distributed Systems

These systems normally have the compressors located near the evaporator in the display case, distributed throughout the supermarket. These systems can use a water loop to connect all the compressors with a remote cooling unit to reject waste heat. Without the long lines from the compressor room to the display cases, refrigerant charge for distributed systems can be reduced by 75 to 80%. The reduction in piping connections and valves also means lower refrigerant losses; 1996 estimate of distributed system refrigerant emissions was 5% per year, eventually dropping to 2% per year (23).

Supermarket Refrigeration – Secondary Loop Systems

Secondary loop systems (heat transfer fluid circulated through display case cooling coils) should have similar reduction in refrigerant charge, refrigerant piping connections and valves, as distributed systems. Refrigerant emission estimates are 4% per year, dropping to 2% per year (23). Secondary loop systems have had higher installation costs than direct expansion systems, and cost effectiveness analysis should be part of system selection criteria.

Summary of Refrigerant Emission Reductions

Trends of refrigerant emission reductions (North American equipment) from the 1980's to the present and to the future are presented in Figure 4. Refrigerant emissions are described in terms of percent of refrigerant charge lost per year. Included are all the types of losses such as system leaks, losses during servicing, and during final refrigerant recovery.

CONCLUSIONS

1. Industry, environmental groups, and governmental agencies have cooperated over the last two decades to bring about dramatic reductions in refrigeration and air conditioning systems energy consumption and refrigerant emissions. The reductions have been possible through a combination of factors: increased environmental impact awareness, commitment of industry personnel, improved systems technology and operating/service procedures, and governmental regulations.
2. These successes give us great confidence in continuing efforts for reduction of climate change impact of refrigeration and air conditioning system.
3. HFC refrigerants have high societal value in providing safe and reliable refrigeration and air conditioning. At equivalent costs of other options, climate change impact from minimal refrigerant emissions can be more than offset by improved energy efficiency.

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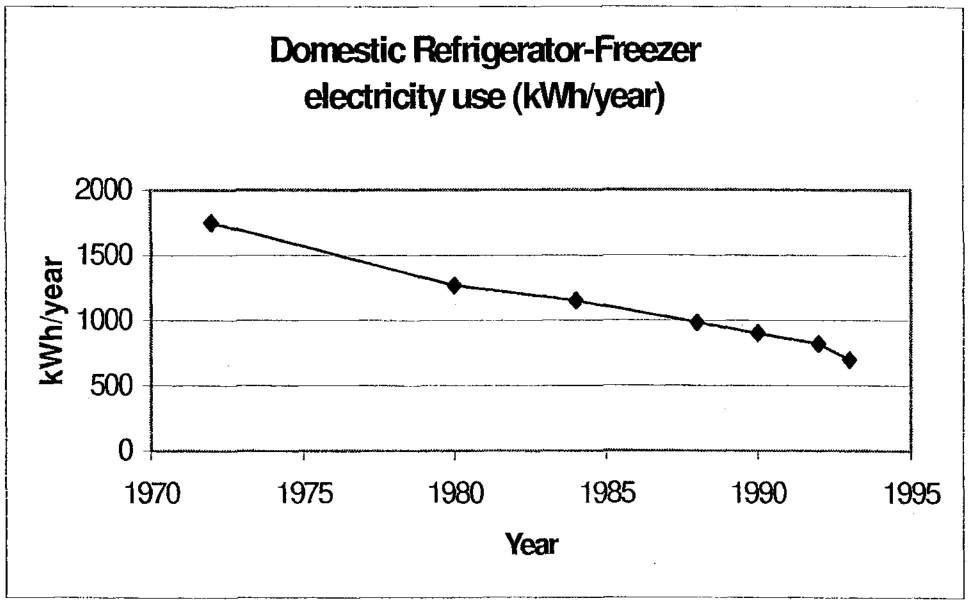

Figure 1. Domestic Refrigerator-Freezer Electricity Use Data Unit with 570 liter internal volume (United States, Reference 5).

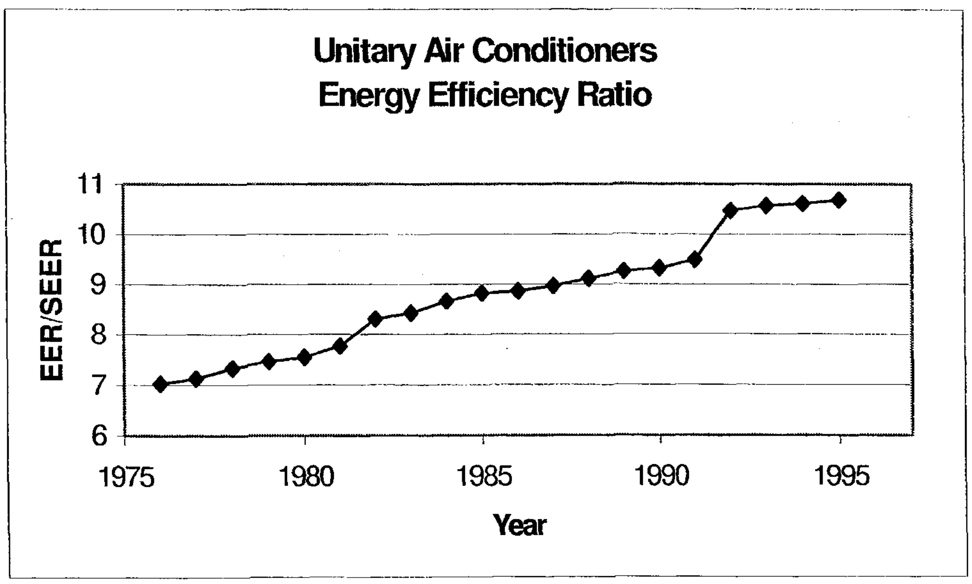

Figure 2. Unitary Air Conditioner Energy Efficiency Ratio for United States shipments. Data from ARI (Reference 6).

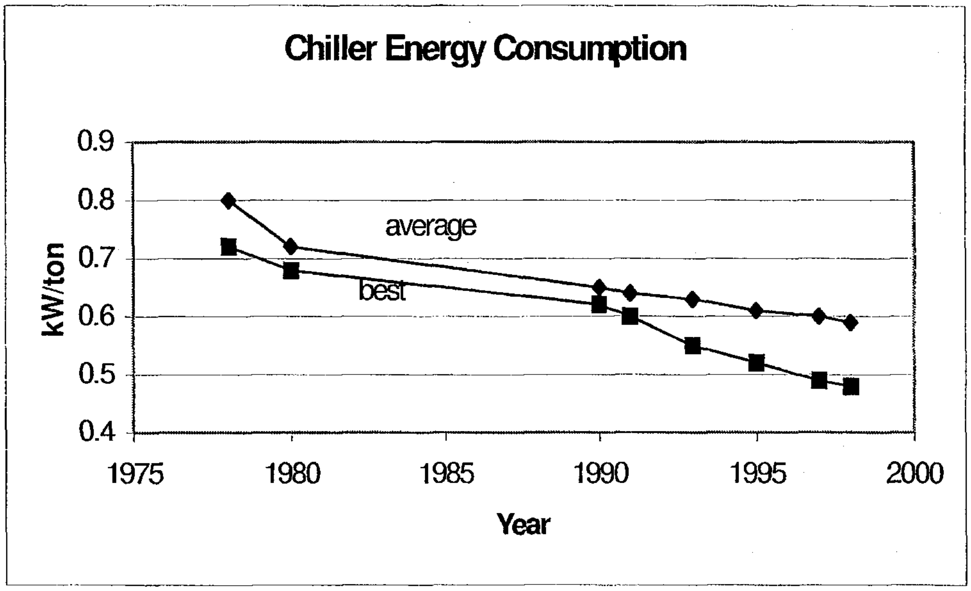

Figure 3. Centrifugal Chiller Energy Consumption Data
United States shipments, Reference 7.

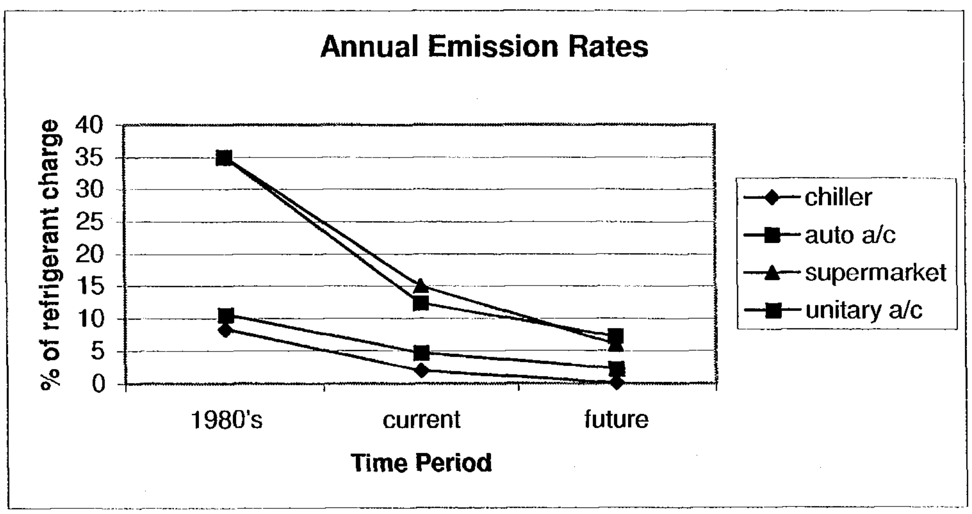

Figure 4. Trends in Refrigerant Emission Reductions
Data and estimates from equipment in United States
References 13 – 23.